REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
May 27, 1996

3. REPORT TYPE AND DATES COVERED
Annual Summary : 6/1/95- 5/31/96

4. TITLE AND SUBTITLE
Josephson Sound in Superfluid Helium

5. FUNDING NUMBERS
PE 61153N
G N00014-94-1-0043

6. AUTHOR(S)
Richard Packard

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of California at Berkeley
Department of Physics
c/o Department Office
366 LeConte Hall
Berkeley, CA 94720-7300

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
ONR 331
800 N. Quincy Street
Arlington, VA 22217-5660

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

19960725 057

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release: distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
This project is directed toward detecting and quantifying a new physical phenomenon characterized by an acoustical field generated near a submicron aperture by quantized phase slip events in superfluid ^{4}He. The sound frequency is determined by the Josephson frequency relation. We have developed several techniques and devices including: a system which can drive superfluid through the aperture at constant pressure head (Josephson frequency) as small as 10^{-4} Pa; an improved cryogenic valve to isolate the acoustic cavity; a vacuum-backed cryogenic microphone with adequate sensitivity to detect the phenomenon; a virbration isolation system. Preliminary experiments have revealed a source of non-acoustic pressure drop which has lead to a new understanding of dissipation within the cell. Measurements have also revealed a new insight into the intrinsic critical velocity near T.

14. SUBJECT TERMS
Superfluid, Josephson effect, phase slips, SQUID

15. NUMBER OF PAGES
5

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

Annual Summary Report
Grant # N00014-94-1-0043
Josephson Acoustic Radiation in Superfluid Helium
May 1996

Brief Description

When superfluid ^{4}He is accelerated by an impressed pressure head, ΔP, through a small aperture, the velocity field is believed to be periodically modulated by abrupt velocity decrements, resulting from the passage of single quantized vortices across the aperture. These so called 2π phase slip events, occur at a frequency derived by the Josephson phase evolution equation: $f_j = \Delta P/\rho\kappa$, where ρ is the fluid density and $\kappa=h/m_4$, is the quantum of circulation.

The goal of this project is to observe, for the first time, an acoustical field generated near a submicron aperture, which serves as the nucleation center for quantized phase slips. The investigators seek to demonstrate that the frequency of the acoustic signal is given by the Josephson frequency relation

By studying the spectral width of the Josephson sound it is expected that one can determine the fluctuation processes underlying the phase slip nucleation. These fluctuations are the limiting factor in the sensitivity of a superfluid gyroscope. The spectral width of the Josephson sound will be studied as a function of temperature.

An associated goal is to provide training in fundamental acoustics at the graduate level.

Experimental Approach

An aperture is placed at one end of an acoustic resonator. Superfluid is forced through the aperture under a pressure head ΔP, a parameter which is monitored by a very sensitive pressure transducer. The phase slips occurring in the aperture excite the resonant modes of the cavity. The cavity is terminated with a sensitive cryogenic microphone.

The entire apparatus must be cooled to cryogenic temperatures and temperature gradients between the cavity and the pressure drive system must be minimized. The apparatus must be isolated from the outside filling lines with superleak-tight cryogenic valves.

In addition to the Josephson-sound apparatus itself, it is necessary to maintain the in-house technology for attaining very low temperatures (possibility down to mK levels) and for manufacturing submicron apertures.

Techniques must be developed to push fluid at constant ΔP while the sound amplitude in the cavity is monitored.

Accomplishments During the Past Year

1. We have made an improved cryogenic valve based on a Torlon valve stem and a polished valve seat. Several such valves have been constructed and found to be satisfactory for use in the present experiment and more general cryogenic superfluid research.

2. The feedback method to drive flow at constant ΔP has been improved and used to make some preliminary measurements of aperture mass current vs. ΔP.

3. The measurements (#2 above) have reveled several significant features:
a. The flow is characterized by the intrinsic critical velocity for the creation of phase slips. This is a necessary condition for the creation of the Josephson sound.
b. We discovered a subcritical resistive flow regime. This resistance causes a chemical potential drop across the aperture but would not be included in the Josephson sound formula.
c. We developed a theoretical model of the above effect and now understand how to incorporate it into the experiment. We have tested the model in a related apparatus and find good agreement between the theory and the experiment.

4. The constant ΔP flow apparatus was used to make a preliminary study of the intrinsic critical velocity very near the superfluid transition. This data is very relevant to the success of a planned NASA mission to study transport properties in superfluids in space. This new data is an unexpected and valuable spin off of this Josephson sound experiment.

5. We have developed a simple vibration isolation system to decouple the experiment from environmental disturbances. The isolation system includes a single stage 1Hz roll-off mass/spring system and a magnetic eddy current damper. We have also constructed a rudimentary acoustic isolation shield for the entire dewar system

6. We discovered that low frequency parasitic modes in the cell can lead to temperature differences across the aperture. The resulting chemical potential difference could not be controlled by the constant ΔP drive

system. A new design has been created that attempts to minimize this effect.

7. We have developed and tested a freestanding, vacuum backed condenser microphone with a position sensitivity of 10^{-14} m/Hz$^{1/2}$. The microphone was placed at one end of a superfluid-filled resonant cavity. The other termination included a calibrate, piezo-electric, volume displacement source. The source was driven with a sawtooth waveform that corresponded in amplitude and frequency to the expected Josephson sound signal. The observed S/N implies that the expected Josephson sound signal will be detectable, in agreement with our earlier estimates.

8. A new student, replacing a graduating member of our team, has been trained to manufacture microapertures. He has successfully recovered the etching techniques and has been able to manufacture a variety of aperture patterns. This student has also received training in the operation of one of our dilution refrigerators so that we can use that technology to study the Josphson sound at lower temperatures than in the present apparatus.

9. Based on our experience with the constant ΔP driver, an improved "double diaphragm" apparatus is being developed. The new design is simpler to construct and will have fewer parasitic modes. It should also be less susceptible to outside vibration.

10. To carry on the acoustics project when the primary student graduates, we have started training a new student in cryogenic acoustic techniques. The student has designed and built a superfluid "third sound" cell and learned how to determine the various acoustic normal modes of the system. He has also been developing techniques of cryogenic condenser microphones. This student has also received training in the use of one of our very low temperature cryostats. In the course of his training the student has refurbished our most powerful cryostat so that it will be available for future experiments on Joseph sound and related phenomena.

Publications

A. Journals

1. Vortex Nucleation in Superfluid ^{4}He, J. Steinhauer, K. Schwab, Yu. Mukharsky, J.C. Davis and Richard Packard, Phys. Rev. Lett. **74**, 5056, (1995)
2. The Determination of the Energy Barrier for Phase Slips in Superfluid ^{4}He, J. Steinhauer, K. Schwab, Y. Mukharsky, J.C. Davis and R. E. Packard, J. of Low Temp. Phys., **100**, 281(1995)
3. The Relationship Between the Josephson Frequency and the Arrhenius Rate for Vortex Nucleation in Superfluid ^{4}He, J. Steinhauer, S. Backhaus and Richard E. Packard. Phys. Rev. B, **52** 9654 (1995)
4. Fabrication of a Silicon Based Superfluid Oscillator, K. Schwab, J. Steinhauer and R. E. Packard, accepted for publication in The Journal of Micromechanical System

B. Conference Proceedings

Contributed Papers

1. A new technique for the measurement of intrinsic critical velocities in ^{4}He, S. Backhaus and R.E. Packard, Conference on Quantum Fluids and Solids, Cornell University, Ithaca, NY, June 12-17,1995

2. Recent Results with a Microfabricated Superfluid Oscillator, Keith Schwab and R. E. Packard, Conference on Quantum Fluids and Solids, Cornell University, Ithaca, NY, June 12-17,1995

3. A Microfabricated Superfluid 4He "RF Squid", Keith Schwab, Seamus Davis and Richard Packard, XXI International Conference in Low Temperature Physics, Aug. 8-14, 1996 Prague, Czech Republic.

4. A Method to Maintain Superflow at Constant Pressure Drive, Scott Backhaus and Richard Packard, XXI International Conference in Low Temperature Physics, Aug. 8-14, 1996 Prague, Çzech Republic.

5. The Intrinsic Critical Velocity Near T_λ, Scott Backhaus, Niels Bruckner, Alex Loshak, Keith Schwab and Richard Packard, XXI International Conference in Low Temperature Physics, Aug. 8-14, 1996 Prague, Czech Republic.

6. An Improved Low Temperaure Valve, Neils Bruckner, Scott Backhaus, and Richard Packard, XXI International Conference in Low Temperature Physics, Aug. 8-14, 1996 Prague, Czech Republic.

Invited Paper

Conference on Quantum Fluids and Solids, Cornell University, Ithaca, NY, June 12-17,1995

The Creation of Vortices in Superfluid ^{4}He, Richard Packard

Personnel Associated With the Project

Scott Backhaus, graduate student researcher
Keith Schwab, graduate student researcher
Andrew Schecter, graduate student researcher
Niels Bruckner, graduate student researcher
Israel Schuster, Postdoctoral scientist
Jane Burwood-Hoy, laboratory assistant

Distribution

2 each to: L. Hargrove; Defense Technical Inf. Center; 1 each to: Director, NRL; S. Garrett; J. Maynard; T. J. Hofler; R.M. Keolian; M. Levy; P.L. Marston; O.G. Symko; Form 298 to Adm. Grants. Officer